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(54) **CARRIER HEAD WITH FLEXIBLE MEMBRANE**

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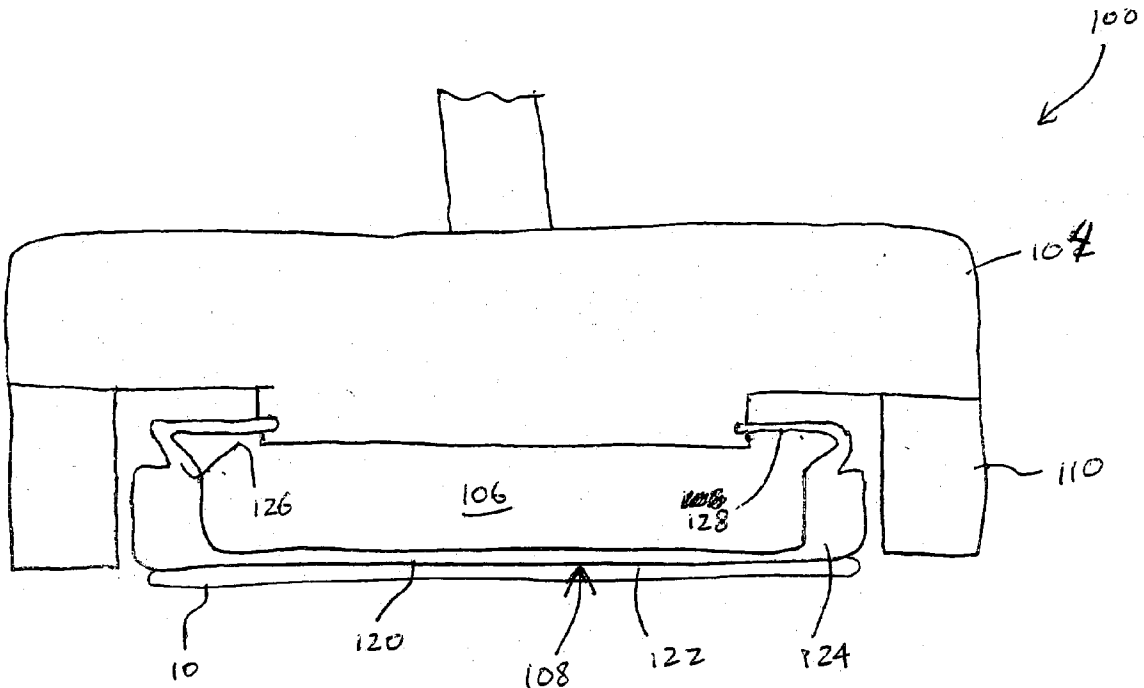
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ABSTRACT

A carrier head for chemical mechanical polishing of a substrate has a flexible membrane extending beneath a base to define a chamber. The flexible membrane provides a substrate receiving surface, and can be configured so that a pressure profile applied to a substrate is substantially insensitive to retaining ring wear.

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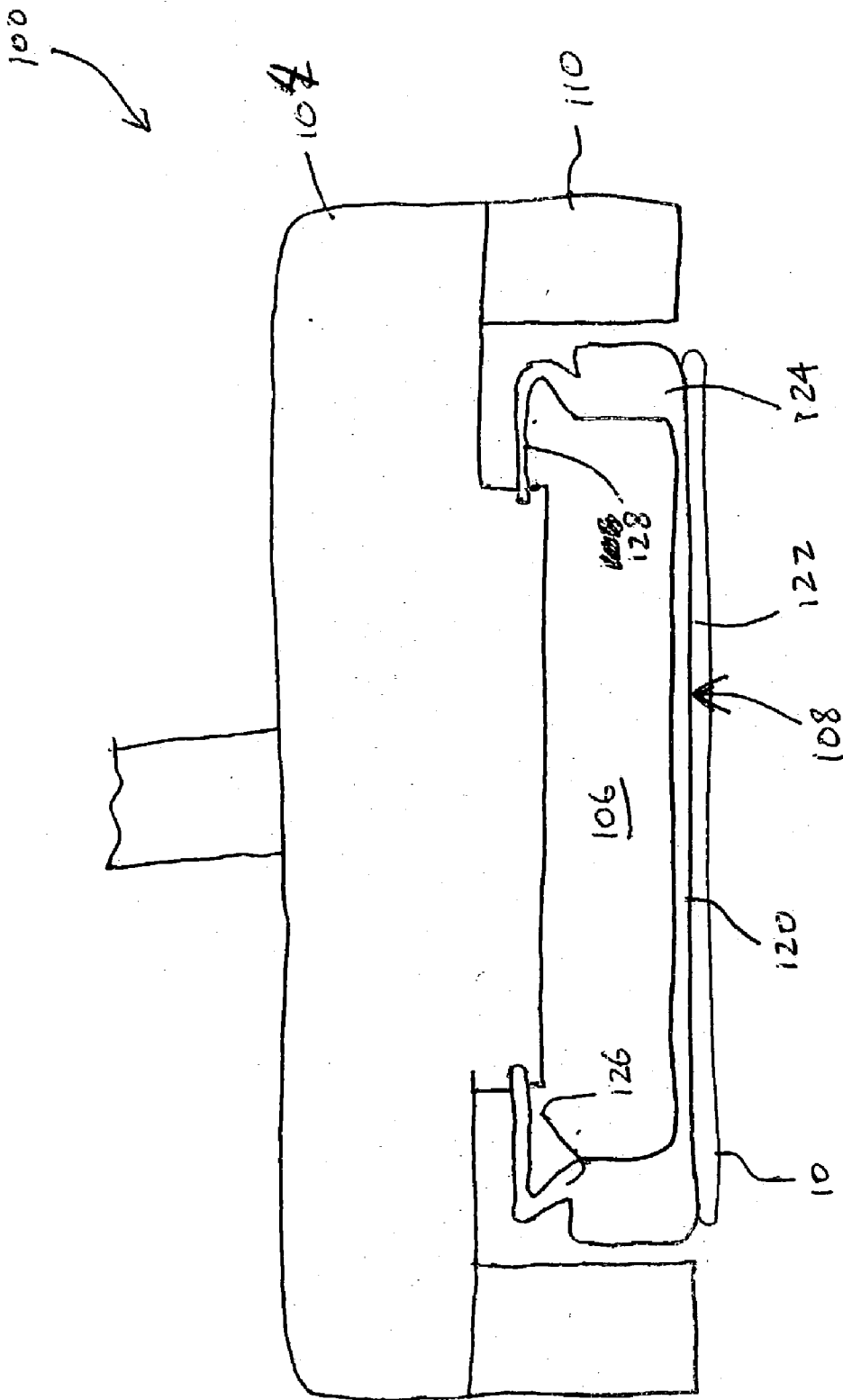


FIG. 1

FIG. 2A

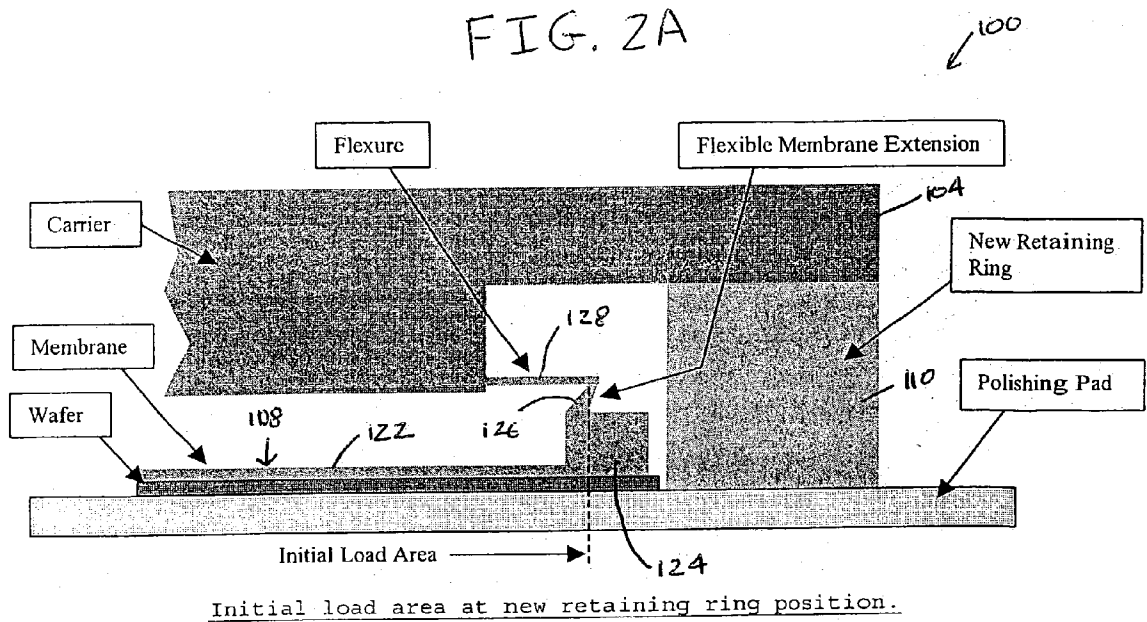
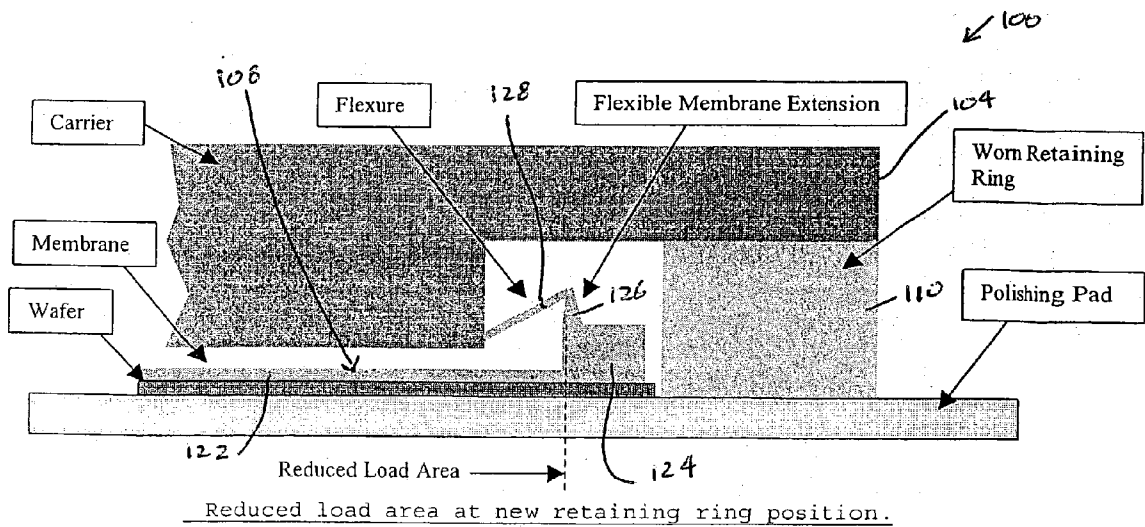
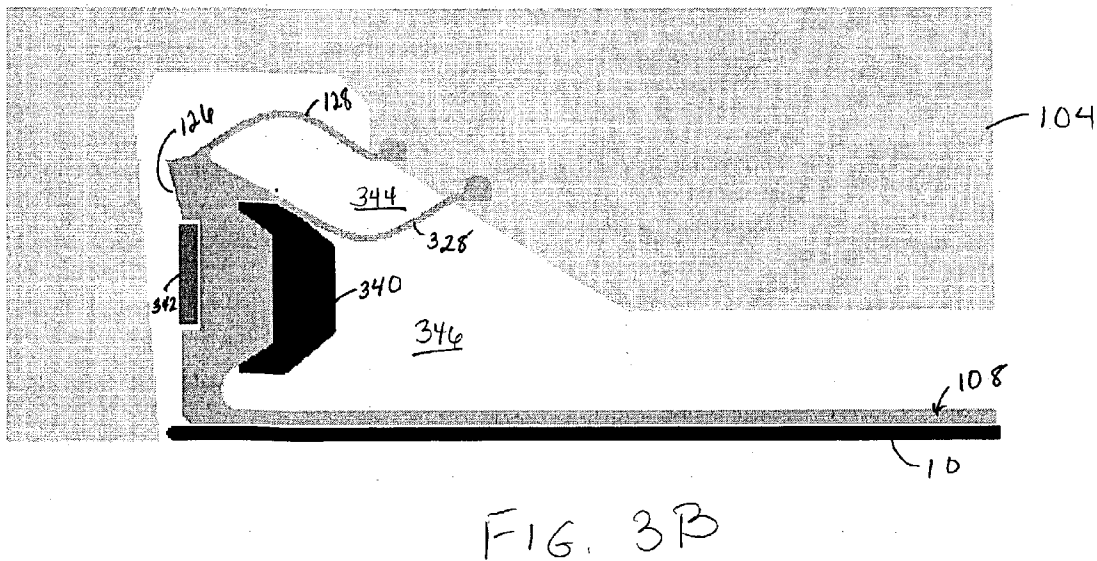
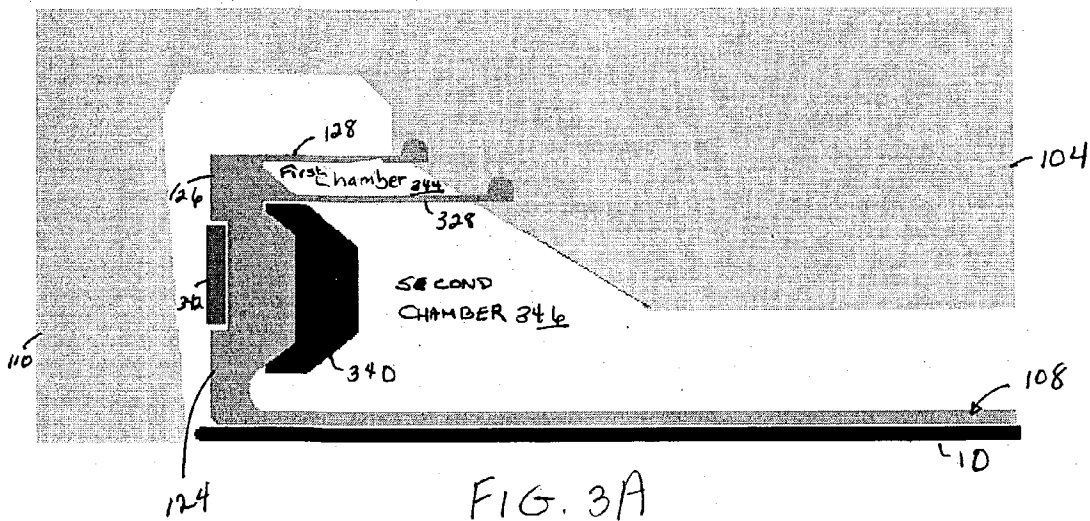


FIG. 2B





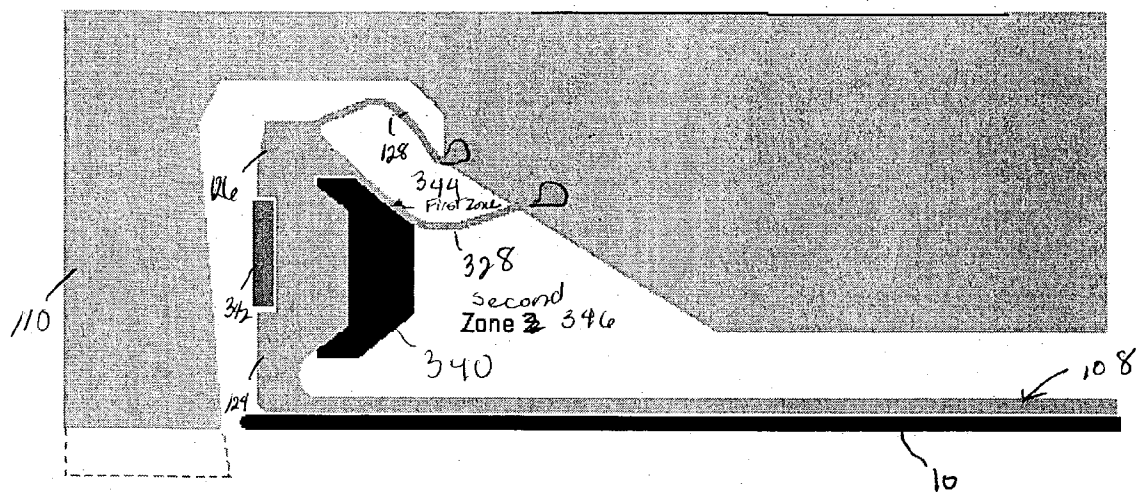


FIG. 3C

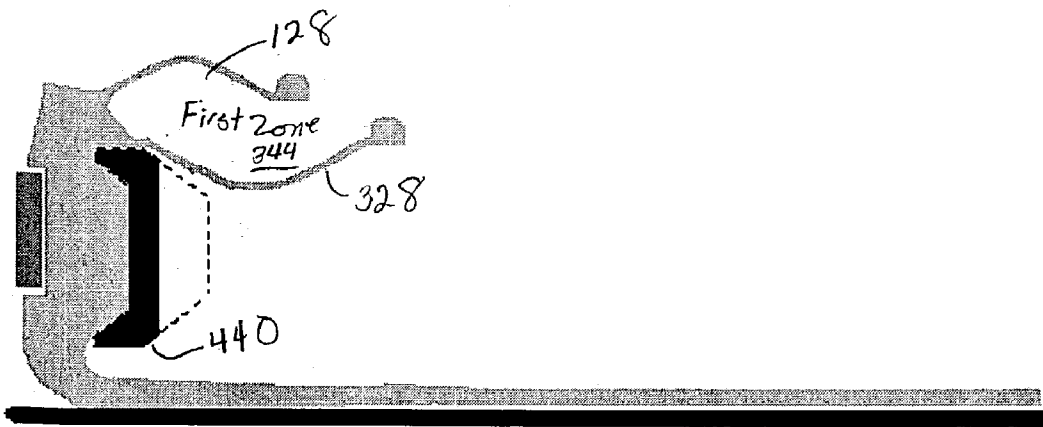


FIG. 4

CARRIER HEAD WITH FLEXIBLE MEMBRANE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to provisional U.S. Application Serial No. 60/370,601, filed on Apr. 5, 2002, which is hereby incorporated by reference in its entirety. This application is also a continuation-in-part of prior U.S. application Ser. No. 09/712,389, filed Nov. 13, 2000, which claims priority to provisional application No. 60/220,641, filed Jul. 25, 2000.

BACKGROUND

[0002] The present invention relates to a chemical mechanical polishing carrier head that includes a flexible membrane, and associated methods.

[0003] Integrated circuits are typically formed on substrates, particularly silicon wafers, by the sequential deposition of conductive, semiconductive or insulative layers. After each layer is deposited, it is etched to create circuitry features. As a series of layers are sequentially deposited and etched, the exposed surface of the substrate becomes increasingly nonplanar. This nonplanar surface presents problems in the photolithographic steps of the integrated circuit fabrication process. Therefore, there is a need to periodically planarize the substrate surface.

[0004] One accepted method of planarization is chemical mechanical polishing (CMP). This planarization method typically requires that the substrate be mounted on a carrier or polishing head. The exposed surface of the substrate is placed against a moving polishing surface, such as a rotating polishing pad. The polishing pad may be either a "standard" polishing pad with a durable roughened surface or a "fixed-abrasive" polishing pad with abrasive particles held in a containment media. The carrier head provides a controllable load to the substrate to push it against the polishing pad. A polishing slurry, including at least one chemically reactive agent, and abrasive particles if a standard pad is used, is supplied to the surface of the polishing pad.

[0005] Some carrier heads include a flexible membrane with a mounting surface that receives the substrate. A chamber behind the flexible membrane is pressurized to cause the membrane to expand outwardly and apply the load to the substrate. Many carrier heads also include a retaining ring that surrounds the substrate, e.g., to hold the substrate in the carrier head beneath the flexible membrane.

SUMMARY

[0006] In one aspect, the invention is directed to a carrier head for chemical mechanical polishing that includes a base and a flexible membrane extending beneath the base to define a chamber and provide a substrate receiving surface.

[0007] In general, in one aspect, the invention features a carrier head for chemical mechanical polishing of a substrate that includes a base, a retaining ring to surround a substrate on a substrate receiving surface and a flexible membrane. The flexible membrane extends beneath the base to define a chamber and provide the substrate receiving surface. The flexible membrane is configured so that a pressure profile applied to a substrate is substantially insensitive to retaining ring wear.

[0008] Particular implementations can include one or more of the following features. The flexible membrane can include a central portion having a substrate receiving portion and a flexure portion having a first end coupled to the base such that an effective load area is reduced as a distance between the first end of the flexure portion and the central portion decreases.

[0009] In general, in another aspect, the invention features a carrier head for chemical mechanical polishing of a substrate that includes a base and a flexible membrane. The flexible membrane extends beneath the base to define a chamber and provide a substrate receiving surface. The flexible membrane also includes a central portion with the substrate receiving portion and a flexure portion having a first end coupled to the base.

[0010] Particular implementations of the invention can include one or more of the following features. The flexure portion can be directly or indirectly connected to the base. The flexible membrane can be configured such that an effective load area is reduced as a distance between the first end of the flexure portion and the central portion decreases. The flexible membrane can include a perimeter portion at an edge of the center portion. The perimeter portion can be less subject to deformation than the central portion. The perimeter portion can be coupled to an internal membrane clamp and/or a support piece.

[0011] The flexible membrane can further include an extension portion connecting the perimeter portion and a second end of the flexure portion. The first end of the flexure portion can be radially inward of the second end of the flexure portion, and the extension can be pulled inwardly.

[0012] The carrier head can include a retaining ring to surround a substrate on the substrate receiving surface. The extension portion can move so that a pressure profile applied to a substrate is substantially insensitive to retaining ring wear. The extension portion can pivot so that an effective load area on the perimeter portion effective is reduced and at least a portion of an increased the load at the edge of the membrane caused by retaining ring wear is offset.

[0013] The flexible membrane can include two flexure portions, each having a first end coupled to the base. The flexible membrane can include a perimeter portion coupled to an internal membrane clamp, the internal membrane clamp located immediately adjacent to a lower of the two flexures and configured to allow free movement of the lower of the two flexures. The two flexures can define two chambers of pressure in the carrier head.

[0014] In general, in another aspect, the invention is features a flexible membrane for use with a carrier head of a substrate chemical mechanical polishing apparatus. The flexible membrane can include a central portion including a substrate receiving portion and a flexure portion having a first end to be coupled to a base of the carrier head. The flexure portion is configured so that a pressure profile applied to a substrate by the central portion is substantially insensitive to relative vertical movement of the vertical position of the central portion relative to the first end of the flexure portion.

[0015] Particular implementations of the invention can include one or more of the following features. The flexible membrane can include a perimeter portion connecting a

second end of the flexure portion to the central portion. The perimeter portion can be less subject to deformation than the central portion. The perimeter portion can be coupled to an internal membrane clamp.

[0016] The flexible membrane can also include an extension portion connecting the perimeter portion to the second end of the flexure portion. The extension portion can pivot when pulled by the flexure portion. The flexure portion can include two flexure portions. The flexible membrane can also include a perimeter portion coupled to an internal membrane clamp and connecting a second end of each flexure portion to the central portion. The internal membrane clamp can be located immediately adjacent to a lower of the two flexures and configured to allow free movement of the lower of the two flexures.

[0017] In general, in another aspect, the invention is features a method of polishing a substrate. The method includes mounting a substrate on a carrier head of a chemical mechanical polishing apparatus so that a first side the substrate is adjacent to the carrier head, the carrier head including a base portion, a retaining ring and a flexible membrane including a central portion providing a mounting surface for the substrate and polishing the substrate using a polishing pad contacting a second side of the substrate on a side opposite from the first side of the substrate. The flexible membrane moves during polishing so that a pressure profile applied to a substrate during polishing is substantially insensitive to ring wear.

[0018] In general, in another aspect, the invention is features a method of operation of a flexure portion of a flexible membrane, the flexure portion connected between a carrier head and a perimeter portion of the flexible membrane. The method includes maintaining a position of a flexure portion that is substantially parallel to a substrate mounted on a central portion of a flexible membrane while a retaining ring of a carrier head maintains its original dimensions, the flexure portion connected at a first end to the carrier head, pivoting an extension portion toward the retaining ring as the polishing progresses, the extension portion connecting a second end of the flexure portion to a perimeter portion of the flexible membrane, and pivoting the extension portion toward the flexure as the retaining ring wears down.

[0019] The invention can be implemented to realize one or more of the following advantages. A flexible membrane is configured so that a carrier head of a chemical mechanical polishing apparatus is less sensitive to retaining ring wear. A flexible membrane includes a flexure portion coupled to a perimeter portion through an extension portion. The extension portion pivots when pulled by the flexure portion as the retaining ring wears, causing reduction of an effective load area on the perimeter portion as the extension is pulled. The flexible membrane is configured so that an effective load area is reduced as a distance between the first end of the flexure portion and a central portion of the flexible membrane decreases.

[0020] The details of one or more implementations of the invention are set forth in the accompanying drawings and the description below. Other features and advantages of the invention will become apparent from the description, the drawings, and the claims.

DESCRIPTION OF DRAWINGS

[0021] FIG. 1 is a cross-sectional view of a carrier head that includes a flexible membrane.

[0022] FIG. 2A is an expanded view of a portion of the carrier head of FIG. 1.

[0023] FIG. 2B illustrates the flexible membrane after a portion of the retaining ring has been worn away.

[0024] FIGS. 3A-3C illustrates the operation of a flexible membrane having two flexures.

[0025] FIG. 4 illustrates a flexible membrane having two flexures and a cut back clamp.

[0026] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0027] As noted above, some carrier heads include a flexible membrane that provides a mounting surface for a substrate and a retaining ring to hold the substrate in the carrier head beneath the flexible membrane. A chamber behind the flexible membrane is pressurized to cause the membrane to expand outwardly and apply the load to the substrate.

[0028] Unfortunately, in some membrane designs, the pressure distribution applied by the membrane can change as the retaining ring wears. Specifically, as the retaining ring wears, the attachment point of the membrane to the rest of the carrier head moves closer to the polishing pad. The lowered attachment point can force the outer perimeter of the membrane downwardly, thereby generating an additional load at the edge of the membrane. Consequently, as the retaining ring wears, the polishing rate at the perimeter of the substrate can increase. If the polishing rate varies as the retaining ring wears, the polishing profile will not be consistent from wafer to wafer. Therefore, it would be useful to have a carrier head that was less sensitive to retaining ring wear.

[0029] Referring to FIG. 1, one or more substrates 10 will be polished by a chemical mechanical polishing (CMP) apparatus that includes a carrier head 100. A description of a suitable CMP apparatus can be found in U.S. Pat. No. 5,738,574, the entire disclosure of which is incorporated herein by reference.

[0030] The carrier head 100 includes a base assembly 104, a retaining ring 110, and a flexible membrane 108. The flexible membrane 108 extends below and is connected to the base 104 to provide a pressurizable chamber 106.

[0031] Although unillustrated, the carrier head can include other elements, such as a housing from which the base 104 is movably suspended, a gimbal mechanism (which may be considered part of the base assembly) that permits the base 104 to pivot, a loading chamber between the base 104 and the housing, one or more support structures inside the chamber 106, or one or more internal membranes that contact the inner surface of the membrane 108 to apply supplemental pressure to the substrate. For example, the carrier head 100 can be constructed as described in U.S. Pat. No. 6,183,354, or in U.S. patent application Ser. No. 09/470,820, filed Dec. 23, 1999, or in U.S. patent application Ser.

No. 09/712,389, filed Nov. 13, 2000, the entire disclosures of which are incorporated by reference.

[0032] Referring to **FIGS. 2A and 2B**, the flexible membrane **108** is formed of a flexible and elastic material, such as neoprene, chloroprene, ethylene propylene rubber or silicone. For example, the flexible membrane **108** can be formed of either compression molded silicone or liquid injection molded silicone. The liquid injection molding process produces a softer material than the compression molding process which increases the ability of a flexure portion **128** of the flexible membrane **108** to pivot, as described below.

[0033] The membrane **108** should be hydrophobic, durable, and chemically inert vis-à-vis the polishing process. The membrane **108** can include a central portion **120** that provides a mounting surface **122** for a substrate, a perimeter portion **124** that extends away from the polishing surface, a flexible extension portion **126**, and an inwardly extending flexure **128** that has an inner edge clamped to the base **104**.

[0034] The central portion **120** of the membrane **108** can include a flexible lip portion as discussed in U.S. Pat. No. 6,210,255, the entire disclosure of which is incorporated by reference.

[0035] The perimeter portion **124** can be less subject to deformation than other portions of the membrane. For example, as shown in **FIGS. 2A and 2B**, the perimeter portion **124** can be relatively thicker than the central portion **120** or flexure portion **128**. Alternatively, the perimeter portion **124** can be formed of a material that is more rigid than the material in other portions of the membrane, or it can include a reinforcing material, or it can extend around a support or spacing structure (see **FIG. 3A**) that prevents deformation.

[0036] The extension portion **126** has a base **130** connected to the perimeter portion **124** and an end **132** connected to the flexure portion **128**. The extension portion **126** is configured so that the end **132** can pivot inwardly in response to pull from the flexure portion **128**.

[0037] As shown in **FIGS. 2A and 2B**, as the retaining ring **110** wears, the attachment point of the flexure **128** to the base **104** moves closer to the polishing pad. As the clamped end of the flexure **128** moves downwardly, the flexure **128** pulls the extension portion **126** inwardly. This reduces the effective load area, e.g., the portion of the load area that covers the perimeter portion **124**, and thereby reduces the load at the edge of the membrane proportionally.

[0038] This reduction in load can compensate for the increased load that results after retaining ring wear. Consequently, an implementation of the carrier head can provide a polishing pressure profile that is more uniform from wafer to wafer. Thus, the polishing process, particularly the polishing rate profile, is more stable and repeatable. In addition, because the process is less sensitive, or substantially insensitive, to retaining ring wear, the retaining ring can be allowed to undergo more wear, and consequently can be used for a longer time before being replaced or repaired. Of course, at sufficiently large wear, the pressure profile becomes sensitive to the retaining ring wear again.

[0039] As shown in **FIGS. 3A-3C**, in another implementation, flexures **128, 328** are attached to the base **104**. The

use of two flexures allows two pressure chambers **344, 346** to be created. This configuration can be used in the carrier head described in U.S. patent application Ser. No. 09/712,389, filed Nov. 13, 2000, the entire disclosure of which is incorporated by reference. Referring to **FIG. 3A**, the initial arrangement of the flexures **128, 328** is substantially parallel to the central portion **120** of the flexible membrane. An annular internal membrane clamp **340**, and an annular support piece **342**, provide reinforcement to the perimeter portion **124** of the flexible membrane.

[0040] The internal membrane clamp **340** and the support piece **342** are formed of a rigid material such as a rigid metal or rigid plastic material. For example, the internal membrane clamp **340** can be formed from stainless steel.

[0041] As pressure in pressure chambers **344, 346** increases, an extension portion **126** begins to pivot outwardly, as shown in **FIG. 3B**. As the outward pivoting of the extension portion **126** increases, the effective pressure area, e.g., the horizontal area within the first pressure chamber **344** which can apply pressure to the perimeter portion **124**, increases. The increase in the effective pressure area causes the load at the edges of the substrate, below the first pressure chamber **344**, to increase. The outward pivoting of extension portion **126** also pulls the two flexures **128, 328** outwardly.

[0042] As retaining ring **110** wears down, the flexible membrane **108** moves up in relation to the base **104**, as shown in **FIG. 3C**. The flexure **128** above the first chamber **344** pulls the extension portion **126** inwardly, which tends to reduce the effective pressure area, reducing the edge load. However, the flexure **328** below the first chamber **344** descends into contact with the internal membrane clamp **340**, and increases edge load. The two effects caused by the inward pulling of the two flexures **128, 328** work against each other. By careful selection of membrane material or taper angle of the internal membrane clamp, these effects can be balanced to reduce or minimize edge load change as retaining ring **110** wears down.

[0043] However, the results of balancing the two effects can be inconsistent, with many variations in the resulting edge load. Focusing only on the effects of the movement of the flexure **128** above the first chamber **344** tends to improve consistency. As illustrated in **FIG. 4**, the edge load effects caused by the movement of the flexure **328** below the first chamber can be reduced by reducing contact between flexure **328** and the internal membrane clamp **440**. The internal membrane clamp **440** is cut back to eliminate or significantly reduce contact between the flexure **328** below the first chamber **344** and a top surface of the internal membrane clamp **440**. Elimination or reduction of contact between flexure **328** and a top surface the internal membrane clamp **440** reduces ring wear sensitivity since flexure **328** is able to move up and down more freely as retaining ring **110** wears, and thus, not affect the substrate edge load.

[0044] A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. For example, the membrane can be secured to different positions on the carrier head, such as being clamped between the retaining ring and the base, or being secured to the retaining ring itself. The flexure can extend outwardly rather than inwardly. The membrane can be attached to a support structure that floats

or rests inside the chamber. Rather than a single-piece membrane, the membrane can be split into multiple membranes. For example, the flexure portion of the membrane could be attached to a support structure, which in turn is attached to the perimeter portion of membrane. In addition, it should be understood, the membrane configuration may still be useful even if the particular shape does decrease sensitivity to retaining ring wear. For example, the carrier head could have a retaining that does not contact the polishing pad, or no retaining ring at all. Accordingly, other embodiments are within the scope of the following claims.

What is claimed is:

1. A carrier head for chemical mechanical polishing of a substrate, comprising:

- a base;
- a retaining ring to surround a substrate on a substrate receiving surface; and
- a flexible membrane extending beneath the base to define a chamber and provide the substrate receiving surface and the flexible membrane configured so that a pressure profile applied to a substrate is substantially insensitive to retaining ring wear.

2. The carrier head of claim 1, wherein the flexible membrane further includes a central portion having a substrate receiving portion and a flexure portion having a first end coupled to the base such that an effective load area is reduced as a distance between the first end of the flexure portion and the central portion decreases.

3. A carrier head for chemical mechanical polishing of a substrate, comprising:

- a base; and
- a flexible membrane extending beneath the base to define a chamber and provide a substrate receiving surface, the flexible membrane including a central portion with the substrate receiving portion and a flexure portion having a first end coupled to the base.

4. The carrier head of claim 3, wherein the flexure portion is directly connected to the base.

5. The carrier head of claim 3, wherein the flexure portion is indirectly connected to the base.

6. The carrier head of claim 3, wherein the flexible membrane is configured such that an effective load area is reduced as a distance between the first end of the flexure portion and the central portion decreases.

7. The carrier head of claim 3, wherein the flexible membrane includes a perimeter portion at an edge of the center portion.

8. The carrier head of claim 7, wherein the perimeter portion is less subject to deformation than the central portion.

9. The carrier head of claim 7, wherein the perimeter portion is coupled to an internal membrane clamp.

10. The carrier head of claim 9, wherein the perimeter portion is coupled to a support piece.

11. The carrier head of claim 7, wherein the flexible membrane includes an extension portion connecting the perimeter portion and a second end of the flexure portion.

12. The carrier head of claim 11, wherein the extension portion pivots when pulled by the flexure portion.

13. The carrier head of claim 11, wherein the extension pivots so that an effective load area on the perimeter portion effective is reduced as the extension is pulled.

14. The carrier head of claim 11, wherein the first end of the flexure portion is radially inward of the second end of the flexure portion, and the extension is pulled inwardly.

15. The carrier head of claim 11, further comprising a retaining ring to surround a substrate on the substrate receiving surface.

16. The carrier head of claim 15, wherein the extension portion moves so that a pressure profile applied to a substrate is substantially insensitive to retaining ring wear.

17. The carrier head of claim 15, wherein the extension pivots so that an effective load area on the perimeter portion effective is reduced and at least a portion of an increased the load at the edge of the membrane caused by retaining ring wear is offset.

18. The carrier head of claim 3, wherein the flexible membrane includes two flexure portions, each having a first end coupled to the base.

19. The carrier head of claim 18, wherein the flexible membrane includes a perimeter portion coupled to an internal membrane clamp, the internal membrane clamp located immediately adjacent to a lower of the two flexures and configured to allow free movement of the lower of the two flexures.

20. The carrier head of claim 3, wherein the two flexures define two chambers of pressure in the carrier head.

21. A flexible membrane for use with a carrier head of a substrate chemical mechanical polishing apparatus, the membrane comprising:

- a central portion including a substrate receiving portion; and

- a flexure portion having a first end to be coupled to a base of the carrier head, wherein the flexure portion is configured so that a pressure profile applied to a substrate by the central portion is substantially insensitive to relative vertical movement of the vertical position of the central portion relative to the first end of the flexure portion.

22. The flexible membrane of claim 21, further comprising:

- a perimeter portion connecting a second end of the flexure portion to the central portion.

23. The flexible membrane of claim 22, wherein the perimeter portion is less subject to deformation than the central portion.

24. The flexible membrane of claim 22, wherein the perimeter portion is coupled to an internal membrane clamp.

25. The flexible membrane of claim 22, further comprising:

- an extension portion connecting the perimeter portion to the second end of the flexure portion.

26. The flexible membrane of claim 25, wherein the extension portion pivots when pulled by the flexure portion.

27. The flexible membrane of claim 21, wherein the flexure portion includes two flexure portions.

28. The flexible membrane of claim 27, further comprising a perimeter portion coupled to an internal membrane clamp, and connecting a second end of each flexure portion to the central portion, the internal membrane clamp located

immediately adjacent to a lower of the two flexures and configured to allow free movement of the lower of the two flexures.

29. A method of polishing a substrate comprising:

mounting a substrate on a carrier head of a chemical mechanical polishing apparatus so that a first side the substrate is adjacent to the carrier head, the carrier head including a base portion, a retaining ring and a flexible membrane including a central portion providing a mounting surface for the substrate; and

polishing the substrate using a polishing pad contacting a second side of the substrate on a side opposite from the first side of the substrate,

wherein the flexible membrane moves during polishing so that a pressure profile applied to a substrate during polishing is substantially insensitive to ring wear.

30. A method of operation of a flexure portion of a flexible membrane, the flexure portion connected between a carrier head and a perimeter portion of the flexible membrane, the method comprising:

maintaining a position of a flexure portion that is substantially parallel to a substrate mounted on a central portion of a flexible membrane while a retaining ring of a carrier head maintains its original dimensions, the flexure portion connected at a first end to the carrier head;

pivoting an extension portion toward the retaining ring as the polishing progresses, the extension portion connecting a second end of the flexure portion to a perimeter portion of the flexible membrane; and

pivoting the extension portion toward the flexure as the retaining ring wears down.

* * * * *